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USING THE CAPNOGRAPH AND MULTICHANNEL RESPIRATORY MASK

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16. Abstract Use of the capnograph and a special breathing mask is described in conjunction with the determination of the CO ₂ transport parameters in human subjects. This method is preferable to those previously employed inasmuch as it requires no puncture of the subject's circulatory system.			
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METHOD FOR RAPID DETERMINATION OF TRANSPORT PARAMETERS OF CO_2 IN MAN
USING THE CAPNOGRAPH AND MULTICHANNEL RESPIRATORY MASKA. M. Shmeleva, I. S. Breslav and B. N. Volkov¹

In order to determine the efficiency of functioning of the respiratory apparatus in man, it is very important to determine the parameters of gas exchange in the organism and in particular the CO_2 tension in the blood. With the development of high-speed analyzers for carbon dioxide (capnographs), such a determination is often made using indirect methods which do not require puncture. However, these methods are still insufficiently used in physiology and medicine because of the methodological difficulties entailed.

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We know that the CO_2 tension in the arterial blood (Pa_{CO_2}) can be evaluated on the basis of the carbon dioxide content in the pulmonary alveoli: because of the high diffusivity of CO_2 its alveoli-arterial gradient in a healthy human being is low [1, 15, 16] and can usually be disregarded. In turn, the content of carbon dioxide in the final portion of expired air (end-tidal gas), which serves as an indicator of alveolar concentration of CO_2 (PA_{CO_2}) is easily determined with the aid of capnography.

It is a much more complicated affair to study the CO_2 tension in mixed venous blood (PV_{CO_2}). As far back as 1909 Plesch [20] showed that under conditions of return respiration, i.e., suspension of gas exchange with the atmosphere, a respiratory mixture achieves equilibrium with respect to the gas tension with mixed venous blood, entering the capillaries of the lungs. Collier [11] studied this principle to determine the PV_{CO_2} with a bloodless method. This method, in its most popular modification [5, 9], is quite

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*Numbers in the right hand margin indicate pagination in the foreign text.

laborous: the subject must first perform reverse respiration from a bag containing oxygen, producing the initial mixture, and then, after resting, rebreathing from the same bag for a final equilibration of the CO_2 in the mixture with the venous blood. Some authors recommend that 3-4 repeated sessions of rebreathing be employed [8, 14]. It is true that modifications have been proposed involving simultaneous rebreathing procedures using a previously prepared gas mixture whose P_{CO_2} is approximately that in the venous blood. However, there is no agreement as far as a number of parameters of this method are concerned: some researchers use a mixture containing 5% [10], others 7-8% CO_2 [4, 17, 18]: either oxygen [10, 18], nitrogen [13] is used as the diluent; the volume of the mixture used by some authors varies from 0.5 to 4 liters, and the duration of rebreathing is 20 seconds to several minutes.

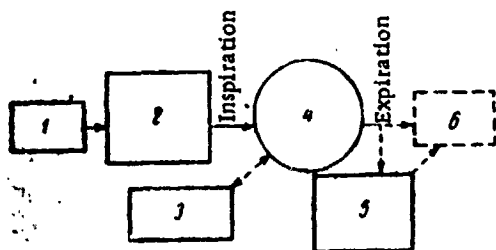


Figure 1. Block Diagram of a Device for Studying Transport Parameters of CO_2 in Man.

1, Tank containing mixtures; 2, Device for Supplying gas mixtures and recording pulmonary ventilation; 3, Bags for rebreathing; 4, Multichannel mask; 5, Mixing reservoir for expired air; 6, Capnograph.

By modifying the methods described, we developed our own method which allows determining the value of the CO_2 tension in the arterial and mixed venous blood in the course of a brief study in man and comparing these data with the intensity of CO_2 production in the organism, determined on the basis of carbon dioxide content in the expired air. This determination can be carried out under conditions of breathing not only air but any other gas mixture. For this purpose, we designed a multichannel respiratory mask with minimum dead space. During the tests the subject breaths through such a mask. The respiratory mixtures come from a device for automatic dispensing of

gas mixtures and recording the parameters of pulmonary ventilation [2].

Dynamic recording of the CO_2 content in the expired air is carried out by a Soviet-made GUM-2 capnograph (Figure 1).

The mask (Figure 2) has three inlet valves, intended for breathing various gas mixtures, an exhaust channel and a rebreathing channel. The electromagnetic

valves which close these channels are controlled by a keyboard switch 1. Contacts 2, 3 and 4 turn on one of the inlet valves which is connected to the device for supplying mixtures and recording ventilation 5, 6, 7. At the same time, exhaust channel 8 opens. The required direction of flow of the air in various phases of the respiratory cycle is ensured by rubber flaps installed in these channels. During each inspiration, air or another gas mixture enters the mask. The expired air is fed through the exhaust channel into the mixing reservoir, a 5-liter bottle, and vents to the outside. When contact 9 is closed, the rebreathing channel 10 is opened, linking the mask to a rubber bag which is initially empty. The remaining channels are then closed.

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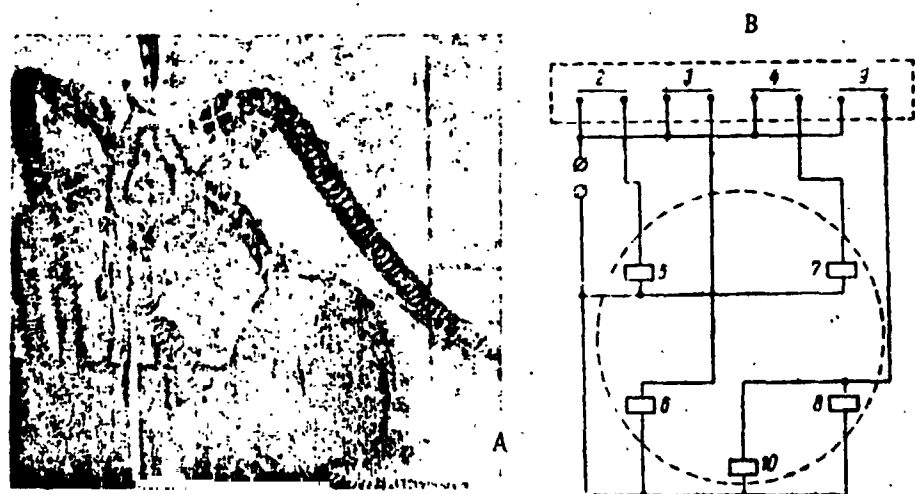


Figure 2. Multichannel Respiratory Mask (A) and a Diagram of the Control Circuit for the Electromagnetic Valves (B).
Explanation in the text.

A portion of the expired air is sampled continuously for analysis on the capnograph either from the mixing vessel or directly from the mask (Figure 1).

To determine the quantity of expired carbon dioxide, the capnograph is connected to the mixing reservoir. A straight line on the capnogram (Figure 3, 1, a) reflects the average content of carbon dioxide in the expired air. If we know the minute volume of pulmonary ventilation, we can calculate the total CO_2 production in the organism (V_{CO_2}).

In order to determine the alveolar content of CO_2 , the intake tube of the capnograph is connected to the respiratory mask. In order to eliminate distortions introduced by the dead space, we carry out the sampling process in such a way that we do not draw simply from the space beneath the mask, but through a catheter fastened inside the mask which passes into the subject's nostril for a depth of about 1 cm. According to our data, this increases the concentration of carbon dioxide gas in the final portion of expired air reaching the capnograph by an average of 0.5%² and makes it possible to obtain a true "alveolar plateau" on the capnogram at the end of each expiration (Figure 3, I, b). On the basis of such a plateau we can calculate the CO_2 tension in the alveolar gas, which, as we said earlier, is primarily arterial.

In determining the CO_2 content in the gas mixture, balanced with mixed venous blood, the procedure is as follows. As we know, if the rebreathing process lasts more than 22-24 seconds, the venous blood which has already passed through the lungs under conditions of suspended gas exchange comes in contact again with the respiratory mixture and is enriched in the tissues by metabolically formed CO_2 . Therefore, for a single determination of P_{CO_2} in the mixed venous blood, the duration of this procedure should be limited to 20 seconds. However, in order for total balancing of the CO_2 between the alveolar gas and venous blood to take place in this period of time, two conditions are necessary: first of all, the P_{CO_2} of the mixture used must be as close as possible to the anticipated value in the veins and secondly the volume of this mixture must not be too great although it should be sufficient for free rebreathing.

We selected a respiratory mixture with the following composition: 7, 8% CO_2 , 8.0% O_2 , 84.2% He. This mixture resembles venous blood, not only with respect to the CO_2 tension (the given volume is somewhat above normal P_{vCO_2} ,

²As soon as the percentage of CO_2 at the end of expiration differs by this value from the alveolar level when using the ordinary method of collecting samples [3].

which provides more reliable results in the determination), but also with respect to the oxygen tension, which is desirable in order to eliminate the influence of the Haldane effect on the binding of the CO_2 by the blood. The helium dilution of the mixture, as was shown by our observations, speeds up the process of equilibration of CO_2 . We established for our volume of mixture equal to the vital capacity of the lungs (VCL) of the subject. This makes it possible to balance the conditions of determination in persons with different VCL. It is convenient in this respect for the person himself to "measure out" the necessary volume of mixture in the course of the study.

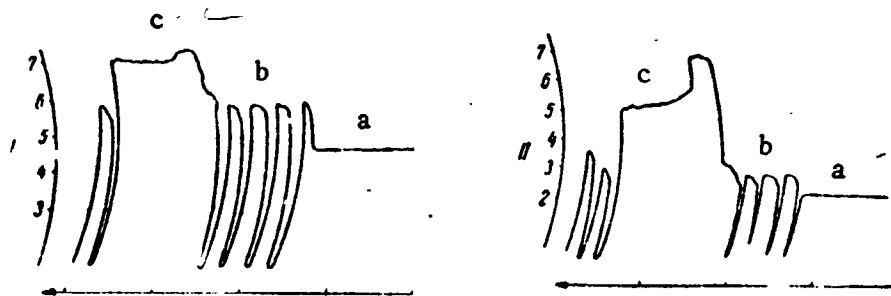


Figure 3. Capnograms Obtained in Determining the Transport Parameters of CO_2 Under Conditions of (I) Normal and (II) Increased Ventilation (Normo- and Hypocapnia). Read from right to left. Left, Scale of percentage of CO_2 . Time marks, 30 seconds. a, Average CO_2 content in the expired air, recorded while sampling from the mixing reservoir; b, "Alveolar plateau" of CO_2 at the end of each expiration; c, 20-second rebreathing of a mixture with 7.8% CO_2 and Balancing of this mixture with CO_2 from their mixed venous blood ("Venous plateau").

In carrying out this test, the subject, on command from the experimenter, takes a deep breath, at the end of which he switches to the channel connected to the supply of a mixture of a given composition. The subject then draws a deep breath of this mixture and at the end of his inspiration switches over to the rebreathing channel, into which he releases his expiration. For a precise accomplishment of the procedure, both at the beginning of the preliminary expiration and while ending the subsequent inspiration, the subject gives light signals addressed to the experimenter. Then he breathes quietly into a

bag and after 20 seconds have passed he again switches over to the noncirculating breathing. During the first 8-10 seconds of rebreathing, the CO_2 content in the lungs-bag system levels off and then, at least for 10-12 seconds, i.e., during 2-3 respiratory cycles one can observe a "plateau" on the capnogram (Figure 3, I, c) which reflects the content of carbon dioxide in the gas mixture, equilibrated with the venous blood. This value is converted to CO_2 tension in the mixed venous blood.

We performed our studies not only with quiet breathing, but also at the end of half an hour of arbitrary hyper- and hypoventilation. As a result, the subject developed a significant hypo- or hypercapnic change in the parameters recorded on the capnogram (an example is given in Figure 3, II). It is particularly important to note that under these conditions the "venous plateau" can be obtained 20 seconds after rebreathing begins.

The determination of all three parameters - \dot{V}_{CO_2} , PA_{CO_2} and Pv_{CO_2} , took 2-3 minutes in all and did not produce any complaints on the part of the subjects. In our opinion, this method possesses sufficient accuracy to be used for the purpose of determining the transport parameters of CO_2 both under experimental and clinical conditions.

The table shows the values that were obtained by us in studying 16 healthy young persons of both sexes in comparison with the data of other authors.

AVERAGE PARAMETERS OF CO_2 TRANSPORT IN MAN (REST, BREATHING AIR)

Authors	V_{CO_2}	PA_{CO_2}	Pa_{CO_2}	PV_{CO_2}	Note	
	(ml/min)	mm Hg				
Albritton [7]	--	--	41.0	46.5	--	
Comroe et al. [12]	200.0	40.0	40.0	46.0	--	
Moser et al. [19]	--	40.0	--	46.0	--	
Severinghaus [22]	--	40.0	41.0	--	--	
Khasis [6]	--	38.7	39.8	49.0	Data presented by age groups, corresponding to our studies.	
Gladkova et al. [3]	--	--	40.0	--		--
Our own data	210.0	39.2	--	46.6		--
σ	± 4.0	± 6.0		± 4.0		--
m	± 1.5	± 2.2		± 1.5		--

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